FINITE ELEMENT ANALYSIS AND EXPERIMENTAL STUDY OF SINGLE POINT INCREMENTAL FORMING OF Ti-6Al-4V FOR BIOMEDICAL SECTOR

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to

Manav Rachna University

by

GIANENDER
Registration No. MRUMEDN012K160407

Under the supervision of

Prof. (Dr.) M.R.Tyagi
Department of Mechanical Engineering
&
Dr. Gulshan Kumar
Assistant Professor
Department of Mechanical Engineering, BITS, Pilani-Dubai Campus

Department of Mechanical Engineering
School of Engineering

Year 2022

Date: 14th Dec. 2022

DECLARATION BY THE SCHOLAR

I hereby declare that the short synopsis entitled **FINITE ELEMENT ANALYSIS AND EXPERIMENTAL STUDY OF SINGLE POINT INCREMENTAL FORMING OF Ti-6Al-4V FOR BIOMEDICAL SECTOR** being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in the Department of Mechanical Engineering under the School of Engineering of Manav Rachna University, Faridabad during the academic year 2022-23.

It is the work that is expected to be carried out under the supervision of **Dr. M.R.Tyagi** and co-supervision of **Dr. Gulshan Kumar**. Further, it is declared that the short synopsis is within the plagiarism limit and copy of the same is attached as per the University norms.

Gianender
Registration No. MRUMEDN012K16047

MANAV RACHNA
Vidyanabarikshai

MANAV RACHNA UNIVERSITY
Declared as State Private University vide Haryana Act 26 of 2014

Date: 14th Dec 2022

CERTIFICATE BY SUPERVISOR(S)

This is to certify that, the short synopsis entitled **FINITE ELEMENT ANALYSIS AND EXPERIMENTAL STUDY OF SINGLE POINT INCREMENTAL FORMING OF Ti-6Al-4V FOR BIOMEDICAL SECTOR** is an original piece of work done by research scholar **Gianender** under the supervision of **Dr. M.R.Tyagi** and co-supervision of **Dr. Gulshan Kumar** for the degree of Doctor of Philosophy in the Department of Mechanical Engineering under the School of Engineering of Manav Rachna University, Faridabad during the academic year 2022-23

Further, it is certified that the short synopsis is within the plagiarism limit and copy of the same is attached as per the University norms.

Gulshan kumar

Supervisor
Prof. (Dr.) M.R. Tyagi
Department of Mechanical Engineering
Manav Rachna University, Faridabad

Co-Supervisor
Dr. Gulshan Kumar
Assistant Professor
Department of Mechanical Engineering
BITS-Pilani, Dubai Campus

ABSTRACT

The method known as incremental sheet forming (ISF) allows for the production of sheet metal components through a succession of minor, incremental deformations. The impact of residual stresses is connected to several process factors during the single-point incremental forming process utilised in the automotive and medical industries, such as tool diameter, tool path, sheet thickness, depth of cut, wall angle, etc. Further improving the ISF process in comparison to other traditional metal forming techniques are the study's comprehensive explanations of the process parameters. The study begins with the introduction of ISF for various types of materials and continues with the measurement of residual stress in diverse industries. Taguchi technique has been used as a design of experiment and optimizing technique for investigation of the process. Forming forces, surface roughness, strain, and formability of the process have been optimized, defining a set of optimal process parameters using Ti-6Al-4V alloy.

Keywords: Negative forming, Process parameters, Forming force, Surface quality, Formability, residual stress, Finite element simulation, Design of Experiments.

CONTENTS

Chapter 1. Introduction 6
1.1 Advantages and Disadvantages of SPIF 7
1.2 Application of SPIF 7
1.3 Titanium Alloys 7
1.3.1 Classification of Ti-Alloy 8
1.3.2 Phase Diagram of Ti-Alloy 8
1.3.3. Alpha-Titanium Alloy 9
1.3.4. Near-Alpha Titanium Alloys 9
1.3.5 Alpha/Beta ($\alpha + \beta$) Alloys 9
1.3.6 Metastable-beta Alloys 9
1.4 Application of Ti Alloy in the Biomedical and Automobile Sector 10
1.5 Flow diagram of the Methodology 11
Chapter 2. Literature Survey 13
Chapter 3. Objectives 17
Chapter 4. Scheme of Chapters 18
Chapter 5. Work plan 19
References 20

Chapter 1. Introduction

A sheet is shaped into the finished workpiece using the incremental sheet-forming process through a sequence of tiny localized deformations. It is simple to create small-batch or bespoke items utilizing this incremental sheet-forming technique (ISF). Stretch forming and the metal spinning process were used to develop the incremental forming technique. Consequently, the ISF method combines the benefits of the stretch forming and metal spinning processes. Single-point incremental forming refers to the incremental sheet forming technique in this research work. There is no supporting reinforcement die utilized on the reverse side of the metal sheet in this specific IF technique, known as single-point incremental forming. Optimizing the process parameters during the SPIF process is another thrust area that has not been explored properly. A clear guideline is required between the process variables and output variables to increase the suitability of the process at the industrial scale (see fig.1)

Literature also reveals that most of the work has been performed on certain aluminum alloys and steel sheets. The influences of process parameters have not been appropriately investigated during the SPIF process on Titanium grade-5 alloy, a biomedical alloy.

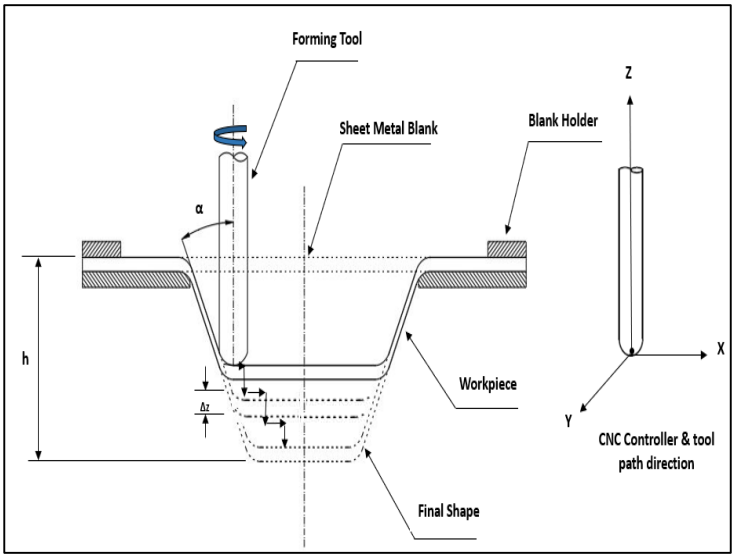


Fig. 1. Schematic representation of Progressive forming deformation process [1]

1.1. Advantages and Disadvantages of SPIF

- Local deformation at the tool sheet interface makes the process capable of having more excellent formability than conventional forming processes.
- In the existence of the positive or negative die.
- Overhead costs are less because they can be done on a conventional CNC machine.
- The process can be executed on a CNC milling machine with the negligible cost of setup.
- The forming forces are smaller than those required by other sheet metal processes like deep drawing.

The following list includes a few of the process' drawbacks:

- Dimensional accuracy is lower than TPIF and DSIF processes. It features geometry flaws at bending points and curves.
- Vertical walls are difficult to be produced using this process.
- Much more forming time is required to form a component.

1.2. Application of SPIF

Single point incremental sheet forming (SPIF) has many applications in a variety of sectors due to the benefits it offers:

The SPIF technique is used to create bespoke bio-medical components, automotive service panels, aircraft fuselage parts, complicated forms, and automotive headlamp casings.

1.3. Titanium Alloys

- Pure titanium crystalline structure experiences a change from hcp gem structure (α- at a lower temperature) to bcc precious stone structure (β-at a higher temperature) by expanding the temperature up to 882°C and the specified single-stage locales are isolated by a two-stage district of α+β [2].
- Alloying components in titanium are usually characterized in two gatherings of α and β balancing out augmentations relying upon whether an expansion or abatement α/β change temperature of 882°C.

1.3.1. Classification of Ti-Alloy

In light of the synthetic structure and microstructure at room temperature, partitioned into various classifications:

- α – combinations alloy
- Near α - combinations alloy
- α + β combinations alloy
- Metastable β combinations alloy
- β combinations alloy

The most widely recognized α - stabilizers are Al, O, N, and C, though numerous overwhelming and high-dissolving change components. Two-stage α + β alloys offer an extensive variety of blends of quality, sturdiness, and high-temperature properties up to ~600°C [3].

Properties of Titanium Compounds

- High-quality to-weight proportion
- Resist corrosion
- High liquefying point (1660°C).
- Non-dangerous
- Provides insurance from UV beams

1.3.2. Phase Diagram of Titanium Alloys

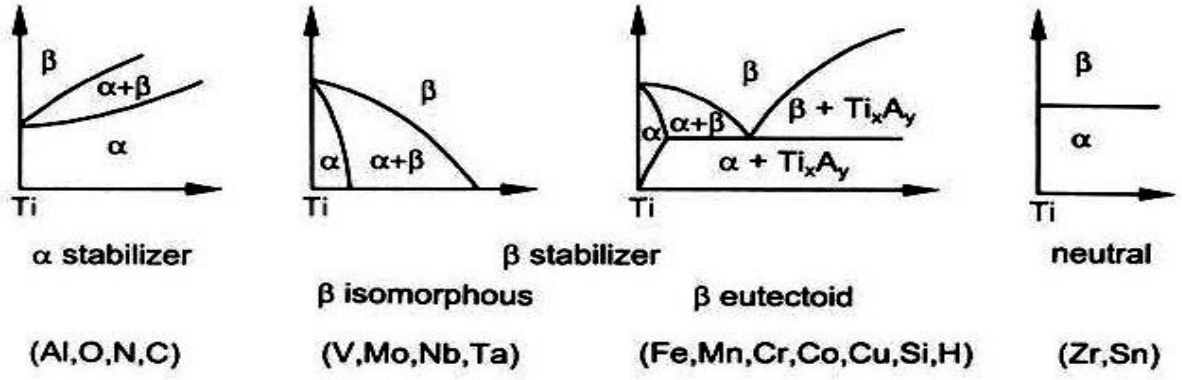


Figure 2. Titanium alloy equilibrium phase diagrams and the impact of alloying additions [4]

1.3.3. Alpha-Titanium Combination alloys

This bunch comprises unadulterated titanium (or unalloyed) and compounds containing α-balancing out components, for example, Al, Ga, Sn, and so forth. The generally utilized alloys are the few evaluations of Indus experimentally unadulterated (CP) titanium, which are, as a result, Ti-O compounds and the ternary piece Ti-5AI-2.5Sn.

Its single-stage materials with moderate rigidities, particularly for low oxygen grades, despite their high warm dependability, prompt sensible crawl qualities. It has excellent malleability, low temperatures, sensible quality, strength, and weldability (see fig.2) [4].

1.3.4. Near-Alpha Titanium alloys

Advancement of these compounds has higher room-temperature elasticity than that shown by alpha composites. They additionally demonstrate the best crawl obstruction of all titanium composites at temperatures over 400°C. Ordinarily, these compounds are produced and warm treated in the "alpha + beta" field with the goal that essential beta grains are constantly present in the microstructure.

1.3.5. Alpha/Beta (α + β) Compounds

These compounds have both α and β stages in harmony at room temperature. They consolidate the quality of α alloys with the pliability of β compounds, and their microstructure and properties can fluctuate generally by fitting warmth medications and thermo-mechanical handling. The measure of reinforcing that can be accomplished is a component of area thickness and synthetic organization of the composite: as the β-settling content builds, the hardenability increments.

1.3.6. Beta, Close Beta, and Metastable-Beta compounds

These sorts of the composite are, for the most part, one that has higher beta stabilizer content than a regular alpha-beta combination; for example, Ti-6Al-4V, however, isn't precisely adequately balanced out to promptly hold an all-beta structure. The Ti-10V-2Fe-3Al compound is a case of a close beta combination [5].

Metastable-beta alloys are significantly more vigorously alloyed with beta stabilizers than close beta composites and promptly hold an all-beta structure upon air cooling of thin areas. Due to the additional soundness of these combinations, it isn't essential to warm treat underneath the β-transus

to advance the beta stage. These combinations are named "metastable" in light of the fact that the resultant of this compound isn't steady; it very well may be matured to hasten alpha for reinforcing purposes. These alloys are so vigorously alloyed with beta stabilizers that the beta stage won't break down to alpha in addition to beta upon consequent maturing. There are no such composites right now being delivered monetarily. A case of such an alloy is Ti-30Mo. The enthusiasm for beta composites comes from the way they contain a high-volume part of beta stage, which can be solidified by alpha precipitation. In this way, these alloys can create very high-quality levels with great malleability.

Also, such composites are considerably more profound hard enable than alpha-beta compounds, for example, Ti-6Al-4V. At last, a significant number of the more intensely alloyed beta alloys show superb cool formability and, in that capacity, offer alluring sheet metal framing qualities [6].

1.4. Applications of Titanium Alloys in the Biomedical and Automobile Sector

Titanium applications, for the most part, are ordered into a few principle gatherings:

- Aviation Applications, for example, motors and airframes.
- Concoction Handling: Numerous compounds preparing tasks indicate titanium to expand hardware lifetime.
- Automobile parts: Especially in motorcycling, hustling, and auto fabricating.
- Consumer Items: It utilized, for example, exhibition outlines, cameras, watches, gems, and different sorts of donning merchandise.
- The biomedical field, for example, carefully actualizes and embeds. Titanium is non-dangerous and, by and large, organically good with human tissues, minerals, and bones.
- Architectural applications: It is ordinarily utilized in outside dividers and roofing materials.

1.5. Flow Diagram of the Methodology

The study focuses on determining suitable process parameters to be optimized from literature and available knowledge of the process. Taguchi technique has been used as a Design of Experiment (DOE) and optimizing technique to investigate the process. Forming forces, surface roughness, strain, and formability of the process have been optimized, defining a set of optimal process parameters. Most significant factors have been suggested for each response of the study with a percentage contribution. Predicted optimal solutions have also been verified with experimental and Finite Element (FE) simulation results using the suggested set of process parameters (see fig.3).

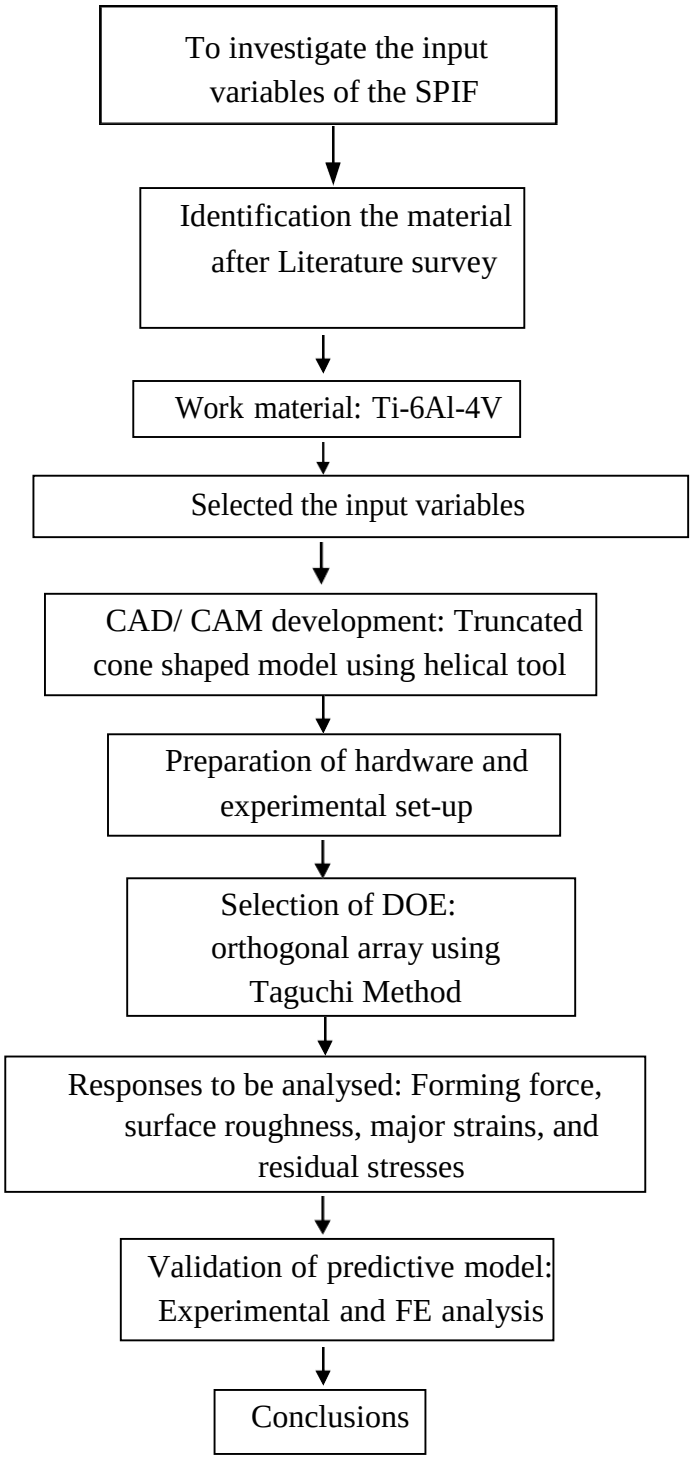

To investigate the input variables of the SPIF
Identification the material after Literature survey
Work material: Ti-6Al-4V
Selected the input variables
CAD/ CAM development: Truncated cone shaped model using helical tool
Preparation of hardware and experimental set-up
Selection of DOE: orthogonal array using Taguchi Method
Responses to be analysed: Forming force, surface roughness, major strains, and residual stresses
Validation of predictive model: Experimental and FE analysis
Conclusions

Figure 3. Flow diagram of the present work

Chapter 2. Literature Survey

The short review of the writing on the significance of the microstructure advancement, surface, texture, residual stresses and mechanical properties amid hot taking a shot at Titanium compounds with its societal results is examined underneath.

Fengyoung Wu et al. [7] explored the isothermal stress investigation of the Ti-55 alloys at the texture temperature run with the variety of strain rate. Microstructure advancement and hot texture conduct were examined of close α - compound.

Weiju Jia et al. [8] utilizing the fashioning procedure to watch the bimodal and lamellar microstructure and rigidity properties of Ti60 Alloys. It saw that the bimodal microstructure displays a higher malleability than that of the lamellar microstructure under all conditions.

XU Wen-Chen et al. [9] examined the mechanical properties and microstructure development of the tubular workpiece of the different titanium alloys. It found that the rigidity increments and prolongation diminish pivotal way as well as circumferential way. It likewise demonstrated that the pliability of the spun workpiece of TA15 composite could be enhanced by strengthening treatment.

Xiaoxin Ye et al. [10] speaks to an exploratory portrayal, i.e., formability, mechanical property, and microstructure development of Ti– 6Al– 4V combination strips under electro plastic moving procedure contrasted and the excellent moving procedure. It demonstrated that the molding nature of electro plastic moved examples is superior to that of chilly moved examples without finding distorted imperfections. It led the examination, i.e., moving isolating power, mechanical property, microstructure advancement, trademark grain limits, stage constitution.

Li Chenwei et al. [11] researched that "hot distortion conduct of beta period of as-cast TC18 titanium alloys in the temperature run 1000-1150°C with the strain rate go 0.01-10s-1 at the twisting level of 70%". The deformation enactment vitality was assessed, for hot working was set up based on factor temperature and strain rate and deciphered by the microstructure perception.

S. Tamirisakandala et al. [12] saw that the oxygen substance and beginning microstructure essentially change the distortion instruments of Ti-6Al-4V amid hot working. While working these alloys, some procedure variable, i.e., strain rate and temperature, essentially impact the distortion system.

Z.L. Zhao et al. [13] investigated the impact of starting microstructure on the texture conduct of Ti60 titanium compound at high-temperature handling in view of the stress-strain information from the isothermal stress test.

Chen Hui-qin et al. [14] broke down the hot twisting practices and microstructure advancements of TC11 in combination with fluctuating the temperature range and strain rate by methods for isothermal stress tests. EBSD procedure was utilized for testing grain limit standard for distortion structures. The outcomes demonstrated that the hot distortion system of this combination is dynamic recuperation joined by geometric powerful recrystallization everywhere strains or spasmodic unique recrystallization in light of the beginning structure states and deformation parameters or softening conduct of the stress-strain bend.

A. Momeni and S.M. Abbasi [15] examined the "hot distortion conduct of the alloys Ti– 6Al– 4V through hot stress tests at temperatures of 800– 1150°C and strain rates running from 0.001 to 1 s-1". The obvious contrasts in stream stress bends got in double single-stage areas were broke down in term of the distinctive reliance of stream worry on temperature and strain rate and diverse microstructural advancements utilizing distinctive procedures.

Jiao Luo et al. [16] investigated the impacts of the strain on the stream stress, the grain measure, and the obvious actuation vitality for twisting of isothermally packed Titanium grade-5 combination at various temperatures run with strain rate. The outcome demonstrated that the relentless and pinnacle stream worry of isothermally packed this alloys diminishes fundamentally with the expansion of twisting temperature.

X.G. Fan et al. [17] considered the "coarse-grained Ti-6Al-4V titanium compound in the β stage locale after isothermal stress to gauge the hot formability and microstructure development of the material". It is discovered that the initial structure does not influence the stream worry after intermittent yielding. It likewise demonstrated that traditional consistent unique recrystallization (CDRX) and a two-advance CDRX happens at high strain rate dependable to make a lace grain structure.

F.S.Qu et al. [18] uncovered the hot twisting conduct of Ti-alloys was portrayed in the variety of temperature scope and the initial strain rate by the constitutive model, the basic states of DRX (Dynamic recrystallization), and EBSD strategies.

Zhou Wei et al. [19] examined the irregular yield conduct of Ti alloys composites, were tried at more than 800°C and in strain rate on a warm recreation testing machine. The outcomes demonstrate that spasmodic yielding shows up at the most noteworthy strain rate and the greatness of irregular yielding increments with expanding the pre-characterized temperature. It utilized the dynamic way to deal with Johnston and Gilman's dynamic yield hypothesis to perceptions of TEM pictures.

Juno Gallegoa et al. [20] prepared by thermomechanical handling, which impacts the microstructure of Titanium alloys composite, were examined by X-beam diffraction and transmission electron microscopy. The investigation demonstrated that the microstructure was made out of ultrafine grains (UFG) of various sizes extend. It additionally demonstrated that ring-type chosen territory electron diffraction designs (SAEDP) recommended the concurrence of low- and high-edge grain limits in the materials.

Ren Guo Guan et al. [21] led the hot stress test on Ti– 6Al– 4V compound fashioning process with three diverse beginning microstructures were first settled by blends of a few warmth medications for the generation of apparatus turn around sit out of gear. It demonstrated that alpha lamellar dispersing fundamentally influences the stream stress; however, the impact of province estimate on stream stress is feeble.

Yanchun Zhua et al. [22] researched the impacts of the preparing parameters on the stream stress conduct and the microstructural advancement in the hot stress of Titanium alloys. The outcomes demonstrate that the stream softening happening at a high strain rate is related to twisting warming, stream unsteadiness, splitting, and DRX, while that happening at a low strain rate is added to DR and DRX. At low temperatures and low decreases discovered, DRX hardly happens, while oxidation breaking is horrifying at high temperature.

H.Z. Niu et al. [23] considered the microstructure advancement, elastic properties, and hot-texture conduct of the Titanium alloys. It demonstrated that enhances the ductile properties altogether due to the microstructure refinement and homogenization with lamellar dividing diminishing amid manufactured composites.

S.Y. Kwak et al. [24] examination between experimental results and numerical outcomes demonstrate that RS significantly affects the stress conduct of mechanical parts. It is likewise

affirmed that remaining stress created amid the assembling procedure is all the more essentially influenced.

F. Gerday et al. [25] demonstrated that Close beta titanium alloys (Ti-5553) are considered alluring materials in the airplane business due to their higher yield quality, magnificent weakness split development opposition, and excellent hardenability properties.

Hiroaki Matsumoto et al. [26] watched the hot texture normal for Ti-6Al-4V alloys' relationship with microstructure advancement at various temperatures and strain rates.

M. Container et al. [27] demonstrated the impact of moderate warming rates on the β stage disintegration of Ti-6Al-4V alloys and during continuous heating were characterized by different experimental techniques.0

S. Bother et al. [28] showed that the attributes of a stage, for example, the substance, size, morphology, and conveyance, to a great extent influence the mechanical properties of beta titanium composite Ti-6Al-4V combination during the SPIF process.

Chapter 3. Objectives

- Residual stresses influence the deformation behavior during the SPIF process.
- Microstructure evolution as a function of deformation at high temperature
- Finite element investigation of residual stress in correlation with microstructure evolution and heat treatment on chemical and mechanical properties of titanium alloys, especially Ti-6Al-4V alloys, will be discussed about its applications.
- Optimizing the SPIF process regarding forming-force, surface roughness, major strains, and material formability using the Taguchi technique.
- To verify the optimal solution suggested by optimizing the technique using the optimal combination of process parameters experimentally and numerically.
- To investigate the effects of significant impact factors on the responses of the process like surface roughness, major strains, and formability of the material

Chapter 4. Scheme of Chapters

Chapter 1: Introduction

This chapter deals with the importance of titanium alloy with biomedical application using the SPIF process. The classification of Titanium alloy with the different chemical composition in the present scenario, historical background, and advantages in aerospace and biomedical science have been discussed. The objective of the present study, the approach involved, description of the hot deformation, especially the SPIF process used, has also been briefly discussed.

Chapter 2: Literature of Review

This chapter discusses detailed literature on microstructure evolution, residual stresses, formability, deformation behavior, and surface texture on Titanium alloys during the single-point incremental forming process. On the basis of a literature survey, a research gap has been identified.

Chapter 3: Experimental Setup

This chapter deals with the experimental setup preparation by the single point incremental forming process to measure their metallurgical aspects, mechanical properties, and deformation evolution of Titanium grade 5 material.

Chapter 4: Analysis

In this Chapter, a mathematical model/simulation model for residual stress impact on mechanical properties of Ti alloys material. The simulation is done through FEM analysis and comparing with experimental approach. A microstructure evolution as a function of deformation at high temperature will be carried out.

Chapter 5: Result & Discussions

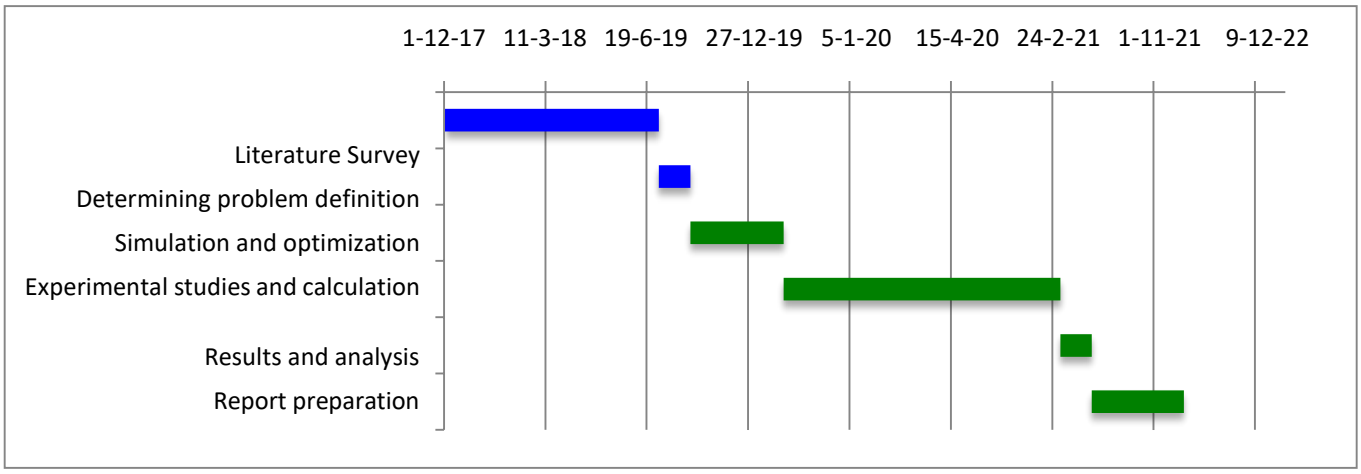
In this chapter, all the results optimized by scanning electron Microscope, EBSD, and X-ray diffraction, followed by simulation through FEM analysis.

Chapter 6: Conclusion & Recommendation

This chapter deals with the essential conclusions of the study. Based upon experience gained during the course of investigation and experimentation, recommendations and suggestions for future work will also be reported.

Chapter 5. Work plan

Work plan for the proposed research is as follows:



References

[1] C. Leyens and M. Peters, “Titanium and Titanium Alloys: Fundamentals and Applications,” Edited by Christoph Leyens, Manfred Peters, Published by WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, First Edition, 2003.

[2] Md Sajid Hussain, “Globularization of a Near α Titanium Alloy,” Master thesis of Engineering in Materials Engineering, Department of Materials Engineering, Indian Institute of Science, Bangalore-560012, July 2011.

[3] www.RMITitanium.com, “Titanium Alloy Guide,” RMI Titanium Company, an RTI International Metals, Inc. Company, Jan 2000.

[4] www.ASM.org, “Titanium and Titanium Alloys,” ASM International web., Materials News Departments, 2013.

[5] Sandvik Materials Technology, “Titanium Alloy”, Sandvik Coromant Web: www.smt.sandvik.com, SE-81181 Sandviken, Sweden2013.

[6] www.TWI.org, “Titanium and titanium alloys,” Weldability of materials, TWI Ltd, Granta Park, Great Abington, Cambridge, CB21 6AL, United Kingdom, 2013.

[7] Fengyong Wu, Wenchen Xu, Xueze Jin, Xunmao Zhong, Xingjie Wan, Debin Shan and Bin Guo, “Study on Hot Deformation Behaviour and Microstructure Evolution of Ti55 High-Temperature Titanium Alloy,” *Metals (Basel).*, vol. 7, no. 8, p. 319, 2017.

[8] W. Jia, W. Zeng, J. Liu, Y. Zhou, and Q. Wang, “Influence of thermal exposure on the tensile properties and microstructures of Ti60 titanium alloy,” *Mater. Sci. Eng*. A vol. 530, no.1, pp. 511–518, 2011.

[9] W. Chen XU, D. bin Shan, Z. long Wang, G. ping Yang, L. Yan, and D. Chang Kang, “Effect of spinning deformation on microstructure evolution and mechanical property of TA15 titanium alloy,” *Trans. Nonferrous Met. Soc. China* (English Ed., vol. 17, no. 6, pp. 1205–1211, 2007.

[10] X. Ye, Z. Thtse, G. Tang, and G. Song, “Retraction notice to Effect of electroplastic rolling on deformability, mechanical property and microstructure evolution of Ti-6Al-4V alloy strip (Materials Characterization, vol.10, (147–161) (10.1016/j.matchar.2014.10.026)),” *Mater. Charact.*, vol. 132, p. 467, 2017.

[11] L. Chenwei, X. Hui, M. Xiaonan, Z. Pengsheng, and H. Zhimin, "High-Temperature Deformation of TC18 Titanium Alloy," *Rare Met. Mater. Eng*., vol. 46, no. 2, pp. 326–332, 2017.
[12] S. Tamirisakandala, B. V. Vedam, and R. B. Bhat, "Recent advances in the deformation processing of titanium alloys," *J. Mater. Eng. Perform*., vol. 12, no. 6, pp. 661–673, 2003.
[13] Z. L. Zhao, H. Li, M. W. Fu, H. Z. Guo, and Z. K. Yao, "Effect of the initial microstructure on the deformation behaviour of Ti60 titanium alloy at high-temperature processing," *J. Alloys Compd*., vol. 617, pp. 525–533, 2014.
[14] H. Qin Chen, C. Xiao Cao, L. GUO, and H. LIN, "Hot deformation mechanism and microstructure evolution of TC11 titanium alloy in the β field," *Trans. Nonferrous Met. Soc. China* (English Ed., vol. 18, no. 5, pp. 1021–1027, 2008.
[15] A. Momeni and S. M. Abbasi, "Effect of hot working on the flow behaviour of Ti-6Al-4V alloy in single phase and two-phase regions," *Mater. Des*., vol. 31, no. 8, pp. 3599–3604, 2010.
[16] J. Luo, M. Li, H. Li, and W. Yu, "Effect of the strain on the deformation behaviour of an isothermally compressed Ti-6Al-4V alloy," *Mater. Sci. Eng*. A vol. 505, no. 1–2, pp. 88–95, 2009.
[17] X. G. Fan, Y. Zhang, P. F. Gao, Z. N. Lei, and M. Zhan, "Deformation behaviour and microstructure evolution during hot working of a coarse-grained Ti-5Al-5Mo-5V-3Cr-1Zr titanium alloy in beta phase field," *Mater. Sci. Eng*. A vol. 694, pp. 24–32, 2017.
[18] F. S. Qu, Y. H. Zhou, L. Y. Zhang, Z. H. Wang, and J. Zhou, "Research on the hot deformation behaviour of a Ti-5Al-5Mo-5V-1Cr-1Fe alloy," *Mater. Des*., vol. 69, pp. 153–162, 2015.
[19] Z. Wei, G. Peng, Z. Yongqing, L. Qian, X. Shewei, and C. Jun, "Discontinuous Yielding in High-Temperature Deformation of Ti-5553 Alloy," *Rare Met. Mater. Eng*., vol. 44, no. 10, pp. 2415–2418, 2015
[20] J. Gallego, T. Santos, R. Zufarovich, and V. Polyakova, "Microstructural Characterization of Ti-6Al-7Nb Alloy After Severe Plastic Deformation 2. Experimental Procedure," pp. 2–7, 2012.
[21] R. G. Guan, Y. T. Je, Z. Y. Zhao, and C. S. Lee, "Effect of microstructure on the deformation behaviour of the Ti-6Al-4V alloy during the compressing process," *Mater. Des*., vol. 36, pp. 796–803, 2012.
[22] Y. Zhu, W. Zeng, Y. Zhao, Y. Shu, and X. Zhang, "Effect of processing parameters on hot deformation behaviour and microstructural evolution during hot compression of Ti40 titanium alloy," *Mater. Sci. Eng*. A vol. 552, pp. 384–391, 2012.

[23] H. Z. Niu, Y. Y. Chen, F. T. Kong, and J. P. Lin, “Microstructure evolution, hot deformation behaviour and mechanical properties of the Ti-43Al-6Nb-1B alloy,” *Intermetallics*, vol. 31, pp. 249–256, 2012.

[24] S. Y. Kwak and H. Y. Hwang, “Effect of heat treatment residual stress on stress behaviour of constant stress beam,” *J. Comput. Des. Eng.*, vol. 5, no. 1, pp. 137–143, 2018.

[25] A. F. Gerday, M. Ben Bettaieb, L. Duchêne, N. Clément, H. Diarra, and A. M. Habraken, “Interests and limitations of nanoindentation for bulk multiphase material identification: Application to the β phase of Ti-5553,” *Acta Mater.*, vol. 57, no. 17, pp. 5186–5195, 2009.

[26] H. Matsumoto, M. Kitamura, Y. Li, Y. Koizumi, and A. Chiba, “Hot forging characteristic of Ti-5Al-5V-5Mo-3Cr alloy with single metastable β microstructure,” *Mater. Sci. Eng. A* vol. 611, pp. 337–344, 2014.

[27] Q. Contrepois, M. Carton, and J. Lecomte-Beckers, “Characterization of the β Phase Decomposition in Ti-5Al-5Mo-5V-3Cr at Slow Heating Rates,” *Open J. Met.*, vol. 01, no. 01, pp. 1–11, 2011.

[28] S. Nag, R. Banerjee, R. Srinivasan, J. Y. Hwang, M. Harper, and H. L. Fraser, “ω-Assisted nucleation and growth of α precipitates in the Ti-5Al-5Mo-5V-3Cr-0.5Fe β titanium alloy,” *Acta Mater.*, vol. 57, no. 7, pp. 2136–2147, 2009.

MANAV RACHNA
vidyanatariksha

Swami Vivekananda Library and Resource Centre
Manav Rachna University

SIMILARITY VERIFICATION CERTIFICATE

Title: "Finite Element Analysis and Experimental Study of Single point incremental forming of Ti-6Al-4V for Biomedical Sector"

Researcher: GIANENDER

Registration Number: MRUMED No12K160407

Supervisor: Dr. M.R. TYAGI

Department: MECH. ENGG.

This is to certify that the above mentioned Short Synopsis/Thesis was scanned for similarity index through Turnitin Software on 14/12/2022 with submission ID 1980848230 and the similarity index was found to be 4 %. The complete report running into 91 Pages, 4010 Word count with File Size 2359 KB is being forwarded to the Research Supervisor/DRC/DRB for review.

Date: 14/12/2022

MANAV RACHNA UNIVERSITY
FARIDABAD
14/12/22

The complete report of the above Short Synopsis/Thesis has been reviewed and the similarity index is below the accepted norms as per the University Grants Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations 2018. The Short Synopsis/Thesis may be considered for further processing

Research Scholar
GIANENDER

Research Supervisor
Dr. M.R. TYAGI

FINITE ELEMENT ANALYSIS AND EXPERIMENTAL STUDY OF SINGLE POINT INCREMENTAL FORMING OF Ti-6Al-4V FOR BIOMEDICAL SECTOR

by Gianender Soe

Submission date: 14-Dec-2022 10:30AM (UTC+0530)
Submission ID: 1980848230
File name: POINT_INCREMENTAL_FORMING_OF_Ti-6Al-4V_FOR_BIOMEDICAL_SECTOR.doc (427K)
Word count: 4010
Character count: 23213

FINITE ELEMENT ANALYSIS AND EXPERIMENTAL STUDY OF SINGLE POINT INCREMENTAL FORMING OF Ti-6Al-4V FOR BIOMEDICAL SECTOR

SHORT SYNOPSIS

by

GIANENDER

Registration No. MRUMEDN012K160407

Under the supervision of

Prof. (Dr.) M.R.Tyagi
Department of Mechanical Engineering
&
Dr. Gulshan Kumar
Assistant Professor
Department of Mechanical Engineering, BITS, Pilani, Dubai Campus

Department of Mechanical

EngineeringSchool of Engineering

MANAV RACHNA UNIVERSITY
Declared as State Private University vide Haryana Act 26 of 2014

Year 2022

ABSTRACT

The method known as incremental sheet forming (ISF) allows for the production of sheet metal components through a succession of minor, incremental deformations. The impact of residual stresses is connected to several process factors during the single-point incremental forming process utilised in the automotive and medical industries, such as tool diameter, tool path, sheet thickness, depth of cut, wall angle, etc. Further improving the ISF process in comparison to other traditional metal forming techniques are the study's comprehensive explanations of the process parameters. The study begins with the introduction of ISF for various types of materials and continues with the measurement of residual stress in diverse industries. Taguchi technique has been used as a design of experiment and optimizing technique for investigation of the process. Forming forces, surface roughness, strain, and formability of the process have been optimized, defining a set of optimal process parameters using Ti-6Al-4V alloy.

Keywords: Negative forming, Process parameters, Forming force, Surface quality, Formability, residual stress, Finite element simulation, Design of Experiments

FINITE ELEMENT ANALYSIS AND EXPERIMENTAL STUDY OF SINGLE POINT INCREMENTAL FORMING OF Ti-6Al-4V FOR BIOMEDICAL SECTOR

ORIGINALITY REPORT

MANAV RACHNA UNIVERSITY FARIDABAD 14/12/22

4%	1%	3%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

Excluding matches less than 14 words

PRIMARY SOURCES

1	"Proceedings of the 13th World Conference on Titanium", Wiley, 2016 Publication	1%
2	Handbook of Manufacturing Engineering and Technology, 2015. Publication	1%
3	link.springer.com Internet Source	1%
4	Peng, Wenwen, Weidong Zeng, Qingjiang Wang, Qinyang Zhao, and Hanqing Yu. "Effect of processing parameters on hot deformation behavior and microstructural evolution during hot compression of as-cast Ti60 titanium alloy", Materials Science and Engineering A, 2013. Publication	1%
5	Z.L. Zhao, H. Li, M.W. Fu, H.Z. Guo, Z.K. Yao. "Effect of the initial microstructure on the deformation behavior of Ti60 titanium alloy at	1%

high temperature processing", Journal of Alloys and Compounds, 2014
Publication

6	www.oalib.com Internet Source	<1 %

Exclude quotes	On	Exclude matches	< 14 words
Exclude bibliography	On		